DEVELOPMENT OF DC-DC CONVERTER FOR DC MOTOR USING FUZZY LOGIC CONTROLLER

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بسم الله الرحمن الرحيم

In the Name of Allah, the Most Beneficent, the Most Merciful

Special dedication to my beloved family,
Yusof Bin Omar (Father)
Allahyarhamah Wan Noor Binti Md Hussain (Mother)
Noraini Binti Mat Ghani (Wife),
Lectures, friends, and siblings who have encouraged, guide and inspired me throughout my journey of education.
Thanks for all the support

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ABSTRACT

When the DC motor is turned on, the start dc motor speed will experience overshoot at the starting speed of the motor. This overshoot will affect the current rise high as if connected to a load. The use of conventional controllers has long been used to control the dc motor and reduce overshoot starting. Fuzzy logic controller is one controller that can be used to control the speed of a dc motor including motor control overshoot starting. To see the effectiveness of fuzzy logic controller in dc motor speed control, a study done by designing a conventional two-Integrated controllers of proportional controller (PI) and proportional-Integrated-Derivatives controller (PID) and compared with fuzzy logic controller. The design of Fuzzy Logic Controller (FLC) does not require an exact mathematical model. Instead, it is design based on general knowledge of the plant. Both three controllers are connected to a dc motor as a load to control the motor speed to the required level. The effectiveness of the designed FLC is compared with designed conventional controllers to examine aspects of starting overshoot, settling time and ripple factor for dc motor speed.

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ABSTRAK

Apabila dc motor dihidupkan, kelajuan permulaan motor arus terus akan mengalami lanjakan semasa permulaan motor. Lanjakan ini akan memberi kesan seperti kenaikan arus yang tinggi jika disambungkan kepada beban. Penggunaan pengawal konvensional telah lama digunakan bagi mengawal motor arus terus dan mengurangkan lanjakan permulaan kelajuan. Fuzzy logic controller merupakan salah satu pengawal yang boleh digunakan untuk mengawal kelajuan sesebuah motor arus terus termasuklah mengawal lanjakan kelajuan permulaan motor. Bagi melihat keberkesanan pengawal logic kabur (FLC) dalam mengawal kelajuan motor arus terus, kajian dilakukan dengan membina dua pengawal konvensional iaitu Proportional-Integrated controller (PI) dan Proportional-Integrated-Derivatives controller (PID). Reka bentuk FLC tidak memerlukan model matematik yang tepat. Sebaliknya, ia adalah reka bentuk berdasarkan kepada pengetahuan am tentang pengawal. Ketiga-tiga penagawal ini disambungkan kepada motor arus terus sebagai beban bagi mengawal kelajuan motor ke tahap yang dikehendaki. Keberkesanan FLC dibandingkan dengan pengawal konvensional dengan meneliti aspek lanjakan permulaan kelajuan motor, penetapan masa dan factor riak bagi kelajuan motor arus terus.

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LIST OF SYMBOLS AND ABBREVIATIONS

D	-	Duty Cycle
T	-	Time
V_S	-	Supply Voltage
V_O	-	Output Voltage
M_V	-	Ratio
V_{REF}	-	Reference Voltage
e	-	Error
ce	-	Change of Error
J	-	Motor Inertia
L	-	Inductance
R	-	Resistance
N_O	-	Output Speed
N_{REF}	-	Reference Speed

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CHAPTER I

INTRODUCTION

1.1 Project Overview

With the rapid changes in development of power electronics, switching element for power supplies are widely applied in various field. DC-DC switching converters are the main components of switching power supplies. DC-DC converters are a class of electronics power circuits that is used extensively in regulated dc power supplies and dc motor drive applications due to its advantages features in terms of size, weight and reliable performance [1]. As an importance branch of power electronics, the investigations on DC-DC switching converters are widely carried out in the world [2].

The idea of using DC-DC converter is to convert fix dc source into a variable dc voltage source or desired dc output source. The output of the DC-DC converter can be higher or lower than the input source depends on the application used. The converter is widely used for motor in electric automobile, forklift truck and others. DC converter can be used in regenerative braking of DC motor to return energy braking into the supply and this feature result in energy saving for transportation system with frequent stop and also used in DC voltage regulation [3].

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In many ways, a DC-DC converter is the DC equivalent of a transformer. There are four main types of converter usually called the Buck, Boost, Buck-Boost and Boost converter. The Buck converter is used for voltage step-down/reduction, while the Boost converter is used for voltage step-up. The Buck-Boost and Cuk converters can be used for either step-down or step-up [4].

A standard approach for speed control in industrial drives is to use a proportional plus integral (PI) controller. Recent developments in artificial-intelligence-based control have brought into focus a possibility of replacing a Pi speed controller with a fuzzy logic (FL) equivalent [5]. Fuzzy Logic speed control is sometimes seen as the ultimate solution for high-performance drives of the next generation. Such a prediction of future trends is based on comparison of the drive response under PI and FL speed control, which has been compared on a number of occasions. Design of a speed controller is always based on the required response for a single operating point [5]. The existing comparisons fall into one of the two categories: speed response with PI and FL speed control for the design case is substantially different or the speed response is more or less the same [5].

Nowadays, the control systems for many power electronics appliances have been increasing widely. Crucial with these demands, many researchers or designers have been struggling to find the reliable controller meet these demands [4]. The idea is to have a control system in DC-DC converter is to ensure desired output speed can be produced efficiently.

In this project, MATLAB/Simulink is used as a platform in designing the fuzzy logic controller (FLC). MATLAB/Simulink simulation model is built to study the speed control of the FLC compared to the PI controller.

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1.2 Problem Statement

DC-DC converter consists of power semiconductor devices which are operated as electronic switches. Operation of the switching devices causes the inherently nonlinear characteristic of the DC-DC converters including one known as the Buck Converter. The switching technique of the Buck converter causes the converter system to be nonlinear system. Nonlinear system requires a controller with higher degree of dynamic response. Proportional-Integral (PI) is one of the controllers used as a switching device for the converter. However the PI controller is known to exhibit sluggish disturbance rejection properties [5].

Classic control has proven for a long time to be good enough to handle control tasks on system control; however his implementation relies on an exact mathematical model of the plan to be controller and not simple mathematical operation [7]. The DC motors have been popular in the industry control area for a long time, because they have enormous characteristics like, high start torque , high response performance, easier to be linear control etc. The proportional integral (PI) controller is the most common form of feedback in the control systems [8].

A study by Zulkifilie Ibrahim and Emil Levi (2002) shows that the PI speed control offers high speed dip and large recovery time when the load is connected. Therefore the implementation of Fuzzy Logic Controller (FLC) that will deal the issue must be investigated. The Fuzzy control is nonlinear and adaptive in nature that gives it robust performances under parameter variation and load disturbances. Since the Buck converter is a nonlinear system, the fuzzy logic controller (FLC) method will be developed to improve overshoot speed at starting of the motor and settling time. The developed FLC has the ability to learn instantaneously and adapt its own controller parameters based on external disturbances and internal variation of the converter. Thus this FLC can overcome the problem stated to obtain better performances in terms of speed control.

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1.3 Project Objectives

The objectives of this project are:

i) To develop a DC-DC Buck Converter using Proportional-Integrated Controller (PI) and Proportional-Integrated-Derivative Controller (PID)

ii) To develop a DC-DC Buck converter using Fuzzy Logic controller (FLC)

iii) To compare the FLC with PI performance in terms of starting speed overshoot, settling time and ripple factor.

1.4 Scope of Project

The scopes of the project are:

i) Modelling the DC-DC Buck converter with DC Motor

ii) Modelling the Proportional-Integrated (PI) and Proportional-Integrated-Derivative (PID) controller for speed control

iii) Modelling the Fuzzy Logic Controller (FLC) controller for speed control

iv) Compare the output speed of the DC motor for both PI and PID with FLC in terms of starting overshoot, ripple factor and settling time.

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CHAPTER 2

LITERATURE REVIEW

2.1 Existing Papers

Fuzzy control also supports nonlinear design techniques that are now being exploited in motor control applications. A thorough literature overview was done on the usage of fuzzy logic controller as applied to DC-DC converter.

K.Viswanathan, D. Srinivasan, R. Oruganti (2002) proposed a universal fuzzy controller and compares its performances at various operating points with local PI controllers designed for the particular points. The settling time and overshoot for start-up and step response obtained by computer simulations have been compared. The simulation result shown the fuzzy controllers achieve good transient response under different operating conditions is clearly established.

Sinan Pravadalioglu (2005) present the feasibility of a high-performance non-linear fuzzy logic controller which can be implemented by using a general purpose was simulated in MATLAB/Simulink. The theoretical and experimental results indicate that the implemented fuzzy logic controller has a high performance for real-time control over a wide range of operating conditions.

Zulkifilie Ibrahima and Emil Levi (2002) proposed a comparison of the drive behaviour under PI and Fuzzy logic speed control. Experimental result indicated that the superiority of Fuzzy logic speed control is less

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pronounced than it often portrayed in the literature on the basis of limited comparisons while the PI speed control provided a superior speed response.

Based on those related work, the researchers make a great effort to propose the good to overcome DC-DC converter problems. Their applications of each method differ, thus the further investigation of this controller is needed.

2.2 DC-DC Converters

DC-DC converters are a class of electronic power circuits that is used extensively in regulated dc power supplies and dc motor drive applications due to its advantageous features in terms of size, weight and reliable performances. The main difficulty in controlling dc-dc converters stems from their hybrid nature as their switched circuit topology entails different modes of operation, each with its own associated linear continuous-time dynamics. Hard constraints are also present on the input variable (duty cycle), and additional constraint may be imposed as safety measures, such as current limiting [1].

DC-DC switching converters are the main components of switching power supplies. As an importance branch of power electronics, the investigations on DC-DC switching converters are widely carried out in the world in which control of converters is one of the hotspots [2].

Modern electronics systems require high-quality, small, light-weight, reliable and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient [5]. In many industrial applications, it is required to convert a fixed-voltage dc source into a variable-voltage dc source. A DC-DC converter converts directly from DC to DC and is simply known as a DC converter. A DC converter can be considered as DC equivalent to an AC transformer with continuously variable turn’s ratio. Like transformer, it can be used to step down or step up a DC voltage source [5].

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DC converters widely used for traction motor in electric automobiles, trolley cars, marine hoists, and forklift trucks. They provide smooth acceleration control, high efficiency, and fast dynamic response. DC converter can be used in regenerative braking of dc motor to return energy bake into the supply, and this feature results in energy 5 saving for transportation system with frequent stop; and also are used, in DC voltage regulation. There are many types of DC-DC convertor which is buck (step down) converter, boost (step-up) converter, buck-boost (step up- step-down) convertor [5].

DC conversion is of great importance in many applications, starting from low power applications to high power applications. The goal of any system is to emphasize and achieve the efficiency to meet the system needs and requirements. Several topologies have been developed in this area, but all these topologies can be considered as apart or a combination of the basic topologies which are buck, boost and flyback [5].

For low power levels, linear regulators can provide a very high-quality output voltage. For higher power levels, switching regulators are used. Switching regulators use power electronic semiconductor switches in ON and OFF states [3].

High-frequency electronic power processors are used in DC-DC power conversion. The function of DC-DC converters are [5]:

1) To convert a dc input voltage V_S into a dc output voltage V_O
2) To regulate the dc output voltage against load and line variations
3) To reduce the ac voltage ripple on the dc output voltage below the required level
4) To provide isolation between the input source and the load (isolation is not always required);
5) To protect the supplied system and the input source from electromagnetic interference (EMI)
6) To satisfy various international and national safety standards

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2.2.1 Buck Converter

The step-down DC-DC converter, commonly known as a buck converter. It consists of dc input voltage source V_S, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R as shown below:

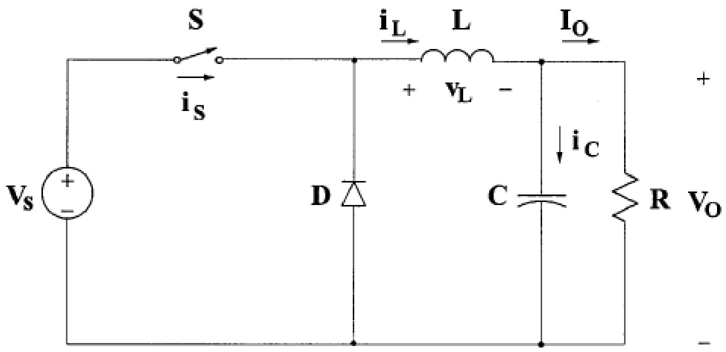

FIGURE 2.1: Equivalent circuit of Buck Converter [10]

The waveform in the converter is shown below under the assumption that the inductor current is always positive [10].

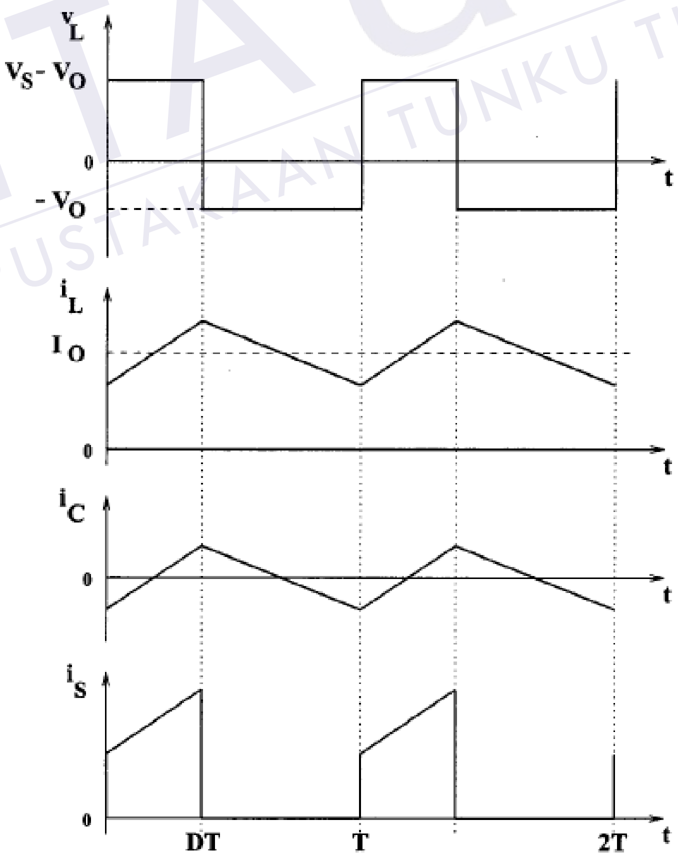

FIGURE 2.2: Output waveform of Buck Converter [10]

It can be seen from the circuit that when the switch S is commanded to the *on* state the diode D is reverse-biased. When the switch S is off, the diode conducts to support an uninterrupted current in the inductor. The relationship among the input voltage, output voltage and the switch duty ratio D can be derived. According to Faraday's law, the inductor volt-second product over a period of steady-state operation is zero. For the buck converter:

$$(V_S - V_O)DT = -V_O(1 - D)T \tag{2.1}$$

Hence, the dc voltage transfer function, defined as the ratio of the output voltage to the input voltage, is:

$$M_V \equiv \frac{V_O}{V_S} = D \tag{2.2}$$

Where D is the duty cycle of the converter

2.3 Fuzzy Logic Controller (FLC)

Fuzzy Logic Controller (FLC) is constitutes a way of converting linguistic control strategy into an automatic by generating a rule base which controls the behaviour of the system. Fuzzy control is control method based on fuzzy logic. Fuzzy provides a remarkably simple way to draw definite conclusions from vague ambiguous or imprecise information [3].

The fuzzy logic foundation is based on the simulation of people's opinions and perceptions to control any system. An expert operator develops flexible control mechanism using words like "suitable, not very suitable, high, little high, much and far too much" that are frequently used words in people's life [7]. Fuzzy logic control is constructed on these logical relationships. There is strong relationship between fuzzy logic and fuzzy set theory that is similar relationship between Boolean logic and classic set theory [7].

Conventional controllers are derived from control theory techniques based on mathematical models of the process. They are characterized with design procedures and usually have simple structures. However in a number

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of cases, when parameter variations take place, or when disturbance are present or when there is no simple mathematical model, fuzzy logic based control systems have shown superior performance to those obtained by conventional control algorithm. Fuzzy control can be described simply as "control with sentences rather than equations". It provides an algorithm to convert a linguistic control strategy – based on expert knowledge-into an automatic control strategy [11].

A typical Fuzzy Logic Controller (FLC) has the following components: Fuzzification, knowledge base, decision making and defuzzification. The performance of the FLC depends very much on the defuzzification process [12]. This is because the overall performance of the system is determined by the controlling signal (defuzzification output of the FLC) the system receives [12]. There are specific components characteristic of a fuzzy controller between the inputs and output.

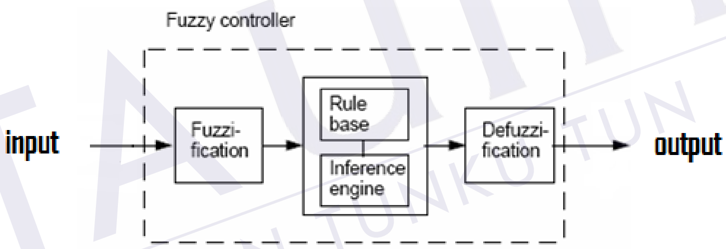

FIGURE 2.3: Structure of FLC [13]

Below is the block diagram of the FLC for DC-DC converters.

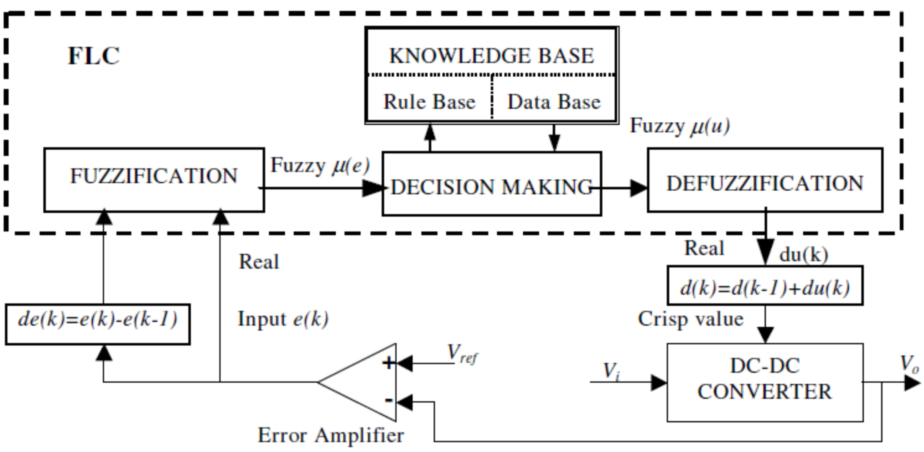

FIGURE 2.4: Block diagram of the FLC for DC-DC converters [14]

According to (Cetin Elmas, Omer Deperlioglu, Hassan Huseyin Sayan)[14] the FLC can be divided into four modules. The first one is fuzzification where used in the classification of input data into suitable linguistic values or sets. The second is knowledge base which includes rule base and data base which contains knowledge of the control rules and linguistic labels while the decision making is the inferring control action from rule base. Lastly the defuzzification is the conversion from the inferred fuzzy value to real crisp value, or control action.

Several researches have contributed in evolving such intelligent controllers for DC-DC converters. The technique of Tse [15] fuzzifies the error and change in error of the output voltage and the Sugeno fuzzy system gives out the change in duty ratio [16]. The [15] has proposed a block diagram of fuzzy for DC-DC Converters as shown in Figure 2 below.

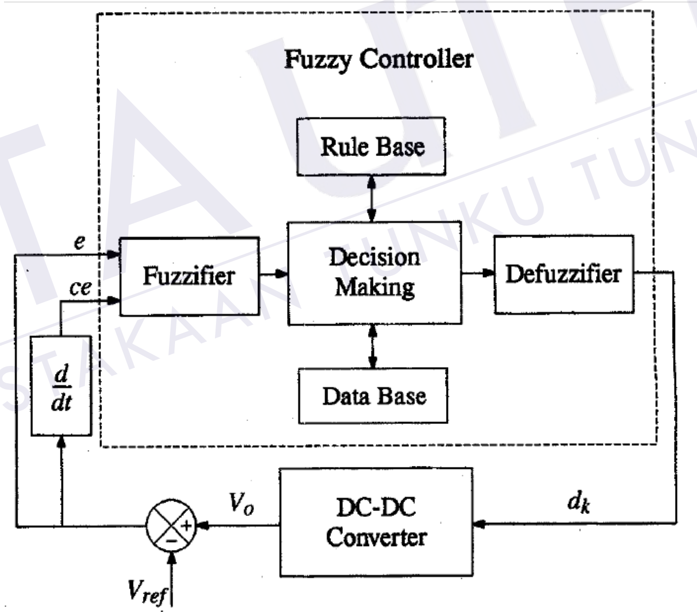

FIGURE 2.5: Block diagram of fuzzy control scheme for DC-DC converters [15]

The input of the fuzzy controller are the error, *e* and the change of error *ce* which are defined as

Error, $e = V_o - V_{ref}$ Change of error, $ce = e_k - e_{k-1}$ (2.3)

Where V_o is the present output voltage, Vref is the reference output voltage and subscript *k* denotes values taken at the beginning of the *k*th switching cycle. The output of the fuzzy controller is the duty cycle and its defined as

$$d_k = d_{k-1} + \eta.\delta d_k \quad (2.4)$$

where δd_k is the inferred change of duty cycle by the fuzzy controller at the *k*th sampling time and η is the gain factor of the fuzzy controller. According to the sum operator, the above equation acts like an integrator and causes to increase system type which result in state error to be zero [9].

A. *Fuzzification*

The first block inside the controller is fuzzification which converts each piece of input data to degrees of membership by a lookup in one or several membership function. The fuzzification block matches the input data with the conditions of the rules to determine. There is a degree of membership for each linguistic term taht applies to the input variable [3].

B. *Decision Making*

One of the key parts in designing the fuzzy controller is its linguistic rules. Knowing the controllable behaviour of process is needed for the improvement of these rules, but there is no need for the mathematical model of the process [9]. The essential part of a fuzzy controller is a set of linguistic rules which is called rule base [11],

1) If error is Negative and change in error is Negative then output is Negative Big.
2) If error is Negative and change in error is Zero then output is Negative Big

C. *Defuzzification*

Defuzzification is when all the actions that have been activated are combined and converted into a single non-fuzzy output signal which is the control of the system [3]. The output levels are depending on the rules that the systems have and the positions depending on the non-linearities existing to the systems [3]. To achive the result, develop the control curve of the system representing the I/O relation of the systems and based on the information, define the output degree of the membership function with the aims to minimize the effect of the non-linearity [13].

The P.Thepsatorn, A.Numsomran, V.Tipsuwanporn, T.Teanthong (2006) had design the fuzzy set in defining output and input where the output of the design is focusing on the duty cycle of the DC-DC converter. The designed FLC is to minimize speed error where the bigger speed error the biggest controller input is expected. For [7] FLC designed uses the error (*e)* and change of error (*ce*) for linguistic variables which are generated from the control rules. The output variable is the change in control variable (*cα*) of motor drive. *Cα* is integrated to achieve desired alpha value. Here *α* is a angular value determining duty cycle of the converter designed.

$$
\begin{aligned}
e(k) &= [w_r(k) - w_a(k)] \times K1_E \\
ce(k) &= [e(k) - e(k-1)] \times K2_{CE} \\
c\alpha(k) &= [\alpha(k) - \alpha(k-1)] \times K3_{CE}
\end{aligned}
\tag{2.5}
$$

Here K1E, K2E and K3cα are each gain coefficients and k is a time index

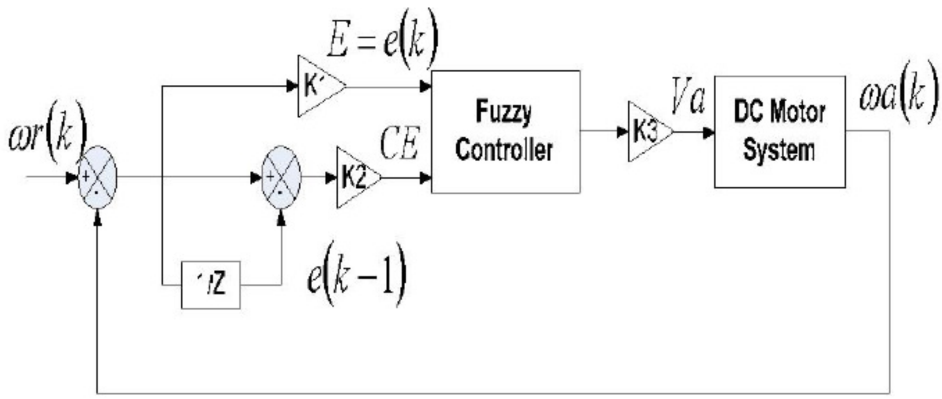

FIGURE 2.6: Block diagram of fuzzy logic controller

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